Risk Evaluation and Management of Disabled Patients during Multi-sensory Environment Interventions through QT-RR relation

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Abstract: 1) Background: Although many studies have supported the efficacy of multi-sensory environment (MSE) in reducing behavioral and psychological symptoms, and improving quality of life for patients with disabilities and caregivers, these studies didn’t offer how to identify a high-risk candidate who would harm from MSE. Thus, this study was to propose a method to classify the high-risk group of cardiac arrest during MSE interventions through the relation between QT and RR intervals (QT-RR interval). 2) Methods: Eight disabled patients were participated in experiments to experience the virtual aquarium for 15 min with a projector and music. The QT-RR relation was measured by electrocardiography, then the risk was evaluated by computing the shortest distance from the mean of QT-RR relation to the standard curve. 3) Results: It was found that the risk of original cardiac arrest for the five patients was averagely 4.7 times higher than that for the three patients. It was considered that the five patients with higher risk came from the 0.6 times slower QT interval. 4) Conclusion: It was concluded that the proposed method to classify the high-risk group through QT-RR relation was good for the prevention of cardiac arrest through the unintended sudden strong stimulation.

Keywords: Cardiac arrest; Electrocardiography; Multi-sensory environment interventions; QT-RR relation; Short QT syndrome.

1. Introduction

Problem behaviors such as hitting, screaming, and wandering may occur as a result of sensory imbalance, and research indicates that environmental factors aimed at restoring equilibrium, such as multi-sensory environment (MSE), may improve the quality of life for patients with disabilities and their caregivers [1]-[3]. Sensory equilibrium may be accomplished within a MSE through controlled visual, auditory, tactile, and olfactory stimuli designed to mitigate overactive or underactive behaviors. This type of MSE intervention has been reported to have a positive impact on behavioral and psychological symptoms (BPS) by reducing wandering, lowering agitation during the bathing process, and increasing positive engagement. This may lead to an improvement in cognition and function, perhaps reducing caregiver burden [4], [5]. Links between emotion and health have long been observed and described. Most of studies have reported that it is important for patients to keep their emotions in balance at all times because cheerfulness can help to alleviate and cure illness, although there is skepticism as to whether mental states can indeed influence physical health [6]-[8]. Thus, many studies support efficacy of MSE in reducing BPS, potentially improving quality of life for patients and caregivers. However, there is limited related works investigating the efficacy of MSE. The studies did
not offer conclusions on the timing of MSE therapy, the frequency with which it should be used, and how to identify candidates who would benefit from MSE therapy [9], [10].

Although MSE interventions should be implemented with careful consideration to the individual preferences and sensitivities of participants in order not to induce BPS through unintended overstimulation, most of studies focused on the only positive impact of MSE on patients with disabilities. However, according to the level and categorization of disability, it is possible to affect the negative impact of MSE on patients with disabilities. Thus, it is considered that the necessity for preliminary checks of healthy condition for patients with disabilities must be discussed.

Therefore, the purpose of the present study was to propose a method to classify the high-risk group of cardiac arrest during MSE interventions through the relation between QT and RR intervals (QT-RR relation). In this study, four patients with muscular dystrophy (MD) and four those with severely motor and intellectual disabilities (SMID) were participated. MD had the clear consciousness to communicate each other, but SMID did not.

2. Human Subjects and Methods

2.1. Human subjects and ethics committee approval

Eight patients with disabilities were participated in the experiment to experience the virtual aquarium for 15 min by a projector and prepared music as audio-visual stimuli: four patients (age: 55.0 ± 13.6 years old, gender: two males and two females) with MD and four those (age: 48.5 ± 0.8 years old, gender: two males and two females) with SMID.

MD [11], [12] causes muscle weakness and muscle loss. Some forms of MD appear in infancy or childhood. Others may not appear until middle age or later. The different types can vary in whom they affect, which muscles they affect, and what the symptoms are. All forms of MD grow worse as the person’s muscles get weaker. Most patients with MD eventually lose the ability to walk, although they have their intentions. All of them in this study had no ability to walk by themselves, thus they could move by their motorized wheelchairs. However, they had a clear consciousness. Furthermore, they could recognize the marine organism such as fish, then track the favorite scene with their free wills. Above all, they had an experience to watch the real aquarium.

SMID [13], [14] is a term used to describe a heterogeneous group of disorders with severe physical disabilities and profound mental retardation, and epilepsy is a frequent complication. SMID is complicated by epilepsy in 70 ~ 80%, and intractable epilepsy is predominant. Some patients achieve seizure control by adolescence, but most do not, and it appears that the prognosis of activities of daily living (ADL) is worse with uncontrolled epilepsy. Most of them had no ability to walk or eat by themselves. They in this study could not move without the help of caregivers or family. They had no clear consciousness. Furthermore, they could not recognize the marine organism, then track the favorite scene with their free wills. They have never been to a real aquarium.

A full explanation of the procedure of the experiment was given to the parents or relatives of the subjects and all questions were answered verbally prior to the study. The parents or relatives provided their written consent and for the publication of the photograph of the subject, the guardian of the subject has given written informed consent. The experimental procedures were performed in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Clinical Trial Center, National Hospital Organization NARA Medical Center in Japan [15] (August 26, 2016).

2.2. Experimental procedure and electrocardiography recordings

All of experiments were performed under the same condition. For Phase 1, a subject moved to the experimental room and then was ready for the measurement for 3 min after setting all of the experimental sensing systems. For Phase 2, a subject attended the virtual aquarium of MSE interventions for 15 min. For Phase 3, a subject moved to the other room of virtual aquarium after eliminating all of the experimental systems.
In order to increase the comfort of all disabled patients during the experiment, a caregiver who was familiar with a patient was always with them. The caregiver also wrote down the condition of his or her patient based on caregivers’ eyes [1]. All of the experiments were performed in the National Hospital Organization NARA medical center in Japan in order to prepare the emergency situation.

Figure 1 shows an overview of experimental environment for MSE interventions. A subject enjoys the movement of many kinds of marine organisms on the projected screen made by curtain while sitting on his own wheelchair. In this study, the room of virtual aquarium consisted of the projector and music was prepared by some volunteers in EPSON Japanese company [16]. For a long duration, they have been dedicating to give disabled patients the virtual aquarium as one kind of surprising events. All subjects could see many kinds of marine organism and ocean scene, then touch the curtain screen, and listen some music tuned with the prepared scene.

The electrocardiography (ECG) (ADInstruments PowerLab) was used for measuring RR and QT intervals [17]. This system was the most powerful DAQ system with 16 analogue input channels, an isolated amplifier such as Bio Amplifier and 2-lead ECG electrodes [18]. At the same time, the thermal imager (Fluke Ti450 which was width × height = 320 × 240 resolution with the sampling frequency of 60 Hz) and the infrared camera (NET COWBOY DC-NCR131 which was a 1.3-megapixel digital...
camera, the sampling frequency of 30 Hz, and width \times height \times depth = 52 \times 70 \times 65 resolution) was used to measure the facial temperature distribution and both the facial expression and body movement.

2.3. QT-RR relation

ECG is the process of recording the electrical activity of the heart over a period of time using electrodes placed on the skin. These electrodes detect the tiny electrical changes on the skin that arise from the heart muscle’s electro-physiological pattern of depolarizing and repolarizing during each heartbeat. Figure 2 shows a description of ECG of a heart in normal sinus rhythm.

The heart rate variability (HRV) time series is a series of consecutive heartbeat time intervals, that is, time intervals between consecutive R-waves in an ECG or simply RR intervals \cite{19}-\cite{21}. The term normal-to-normal is sometimes used when referring these beat-to-beat intervals, merely to indicate that the consecutive QRS complexes result from normal sinoatrial (SA)-node depolarization, excluding for example premature ventricular beats and other arrhythmic events. The term RR is used to denote beat-to-beat intervals resulting from the normal SA-node depolarization. Derivation of RR interval time series from ECG is illustrated in Figure 2. If we assume that the ECG recording includes \( N + 1 \) heartbeats, then the RR interval series has \( N \) data points

\[
RR = (RR_1, RR_2, ..., RR_N). \tag{1}
\]

Meanwhile, the QT interval of a body surface ECG reflects the depolarization and repolarization process across the ventricular myocardium. Since the depolarization process reflected by the QRS complex is relatively stable, the QT interval is clinically used to measure prolongation or shortening of the ventricular repolarization process \cite{22}-\cite{24}. The long QT interval (LQTI) is caused by a range of potassium or sodium ion channel mutations, while the short QT interval (SQTI) is associated with a reduction in repolarization reserve that can be induced by pharmaceutical agents, hypokalemia, or hypomagnesemia. Both LQTI and SQTI conditions have been associated with increased cardiac mortality. However, ventricular repolarization has the intrinsic property of being inversely related to RR intervals, for example, QT interval shortened as RR interval decreases. As a consequence,
an evaluation of QT interval changes must always accommodate for the underlying changes in RR interval. The QT interval series has also \( N \) data points

\[
QT = (QT_1, QT_2, \ldots, QT_N). \tag{2}
\]

By using two Equations 1 and 2, it is possible to calculate the relation between RR and QT intervals (QT-RR relation).

Then, it is important to evaluate how the measured QT-RR relation is suitable for the standard QT-RR relation. QT intervals are dependent on RR intervals and may be adjusted to improve the detection of subjects at increased risk of ventricular arrhythmia. Although modern computer-based ECG machines are able to compute a corrected QT (QTc), this correction may not aid in the detection of subjects at increased risk of arrhythmia. Thus, there are a number of different correction formulas such as Bazett [25] and Fridericia formula [26]. Although many general RR correction formulae have been proposed to normalize the QT to RR using several mathematical functions to correct for RR changes, Fridericia formula was applied for the present study. He studied 50 healthy individuals (age: 3 ∼ 81 years old; 28 males and 32 females) at rest to determine the accuracy and the error rate in the measurement of both the pulse period and the duration of the ventricular ECG. From the obtained data it was possible by mathematical analysis to hypothesize a relationship between the duration of the ventricular ECG and the duration of the pulse period, which can be expressed in the following standard equation:

\[
QT = 8.22 \sqrt{RR}. \tag{3}
\]

By applying this Equation 3 to his data set, Fridericia defined an average error of 0.015 s for a single duration. Variations of the observed duration of electrical systole > 3 times the average error were considered to be pathological. The upper value for a normal QT interval at a heart rate of 60 beat per minute (= 1.0 s) was defined as 0.427 s, and so QT values > 0.430 s were deemed prolonged. Then, SQTII was usually defined as QT values < 0.330 s.

As a result, it is possible to compare the measured QT-RR relation in two Equations 1 and 2 with the Fridericia formula in Equation 3. Autonomic tone influences RR and the QT interval variations. QT and RR may improve characterization of sympathovagal control and estimation of risk of primary cardiac arrest. Thus, evaluation of effects of QT-RR relation from standard is connected to risk of primary cardiac arrest among persons without clinically recognized heart disease.

2.4. Risk evaluation

When we regard the Equation 3 as an approximate line in fixed range, it is possible to evaluate the risk degree of heart disease with the shortest distance from a fixed point to any point on a fixed infinite line in Euclidean geometry. Here, the fixed point indicates the mean value of measured QT-RR relation, and the line indicates the standard of QT-RR relation. In the case of a line in the plane given by the Equation \( ax + by + c = 0 \), where \( a, b, \) and \( c \) are real constants with \( a \) and \( b \) not both zero, the distance from the line to a point \((x_0, y_0)\) is [27]

\[
d = \frac{|ax_0 + by_0 + c|}{\sqrt{a^2 + b^2}}. \tag{4}
\]

In this study, the long distance of \( d \) represents the higher risk, and the short represents the lower risk under the heart condition.
3. Results

3.1. Results of total measured electrocardiography

Figure 3 refers to a 3-dimensional graph where ECG data are arranged as a function of PQRST waves. This graph shows the results of total measured ECG for all of subjects. Figures 3 (a) ~ (d) represent total measured ECG conditions for subjects with MD, and Figures 3 (e) ~ (h) represent those for subjects with SMID. All of accumulated 18 min ECG data including Phases 1 and 2 are monitored by this type of plot. These plots enabled us to understand what kinds of ECG data were used for calculation and how the heart condition for all of subjects was changed during MSE interventions.

All of subjects 1 ~ 4 with MD had the clear R wave. However, the P wave for subject 2 was not clear, although that for subjects 1, 3, and 4 was clear. The Q wave for subjects 2 and 3 was not observed, compared with subjects 1 and 4. It was confirmed that the R wave for subject 2 had some fluctuation at all times. Meanwhile, all of subjects 5 ~ 8 with SMID did not have the clear R wave. The R wave for subject 8 had serious fluctuation randomly. The wave of P, Q, and T for all subjects was not clear.

As a result, the poor heart condition for subject 2 with MD and all subjects 5 ~ 8 with SMID was confirmed. Furthermore, the weak and abnormal R wave for all subjects with SMID looked very serious. The R wave represents the electrical stimulus as it passes through the main portion of the ventricular walls. Because the wall of the ventricles is very thick due to the amount of work they have to do, more voltage is required. That is the reason why the R wave is by far the biggest wave generated during normal conduction.

3.2. Results of QT-RR relation

Figure 4 shows results of QT-RR relation for all of subjects. The horizontal axis indicates the RR interval, and the vertical axis indicates the QT interval. The blue curve line for Fridericia formula as shown in Equation 3 means the standard under the condition of healthy subjects, and the green
Figure 4. Results of relation between QT and RR intervals (QT-RR relation) for all of subjects: (a) and (b) represent results for subjects with muscular dystrophy (MD) for Phase 1 and 2, and (c) and (d) represent results for subjects with severely motor and intellectual disabilities (SMID) for Phase 1 and 2.

straight line for approximate line means the approximated results, that is $0.2x - y + 0.22 = 0$. Then, different color data indicate different subjects.

3.2.1. Results of Phase 1

Figures 4 (a) and (c) show the results of QT-RR relation before MSEs. Figure 4 (a) represents the results for subjects with MD, and Figure 4 (c) represents the results for subjects with SMID.

For the results of subjects with MD for Phase 1, the QT-RR relation for 3 subjects 1, 3, and 4 was existed near the standard curve. RR intervals for three subjects were the mean ± standard deviation (SD) = 0.653 s ± 0.009 for subject 1, 0.926 s ± 0.025 for subject 3, and 0.787 s ± 0.044 for subject 4. QT intervals were 0.329 s ± 0.016 for subject 1, 0.345 s ± 0.006 for subject 3, and 0.339 s ± 0.008 for subject 4. Because the standard curve meant the healthy heart condition, the heart condition for three subjects could be healthy in terms of heart condition. However, the QT-RR relation for subject 2 was apart from the standard curve. The RR interval was 1.250 s ± 0.042, and the QT interval was 0.267 s ± 0.011. Compared with three subjects, the subject 2 showed 1.585 times faster RR and 0.790 times slower QT intervals.

The risk of heart condition was evaluated by the Equation 4. The risk for three subjects was 0.021, 0.059, and 0.037, however, the risk for subject 2 was 0.199. Because the longer distance meant that the
heart condition for any subject was worse, it was considered that the heart condition for subject 2 with MD was 5.099 times worse than three subjects with MD.

For the results of subjects with SMID for Phase 1, the QT-RR relation for all subjects was apart from the standard curve. RR intervals were 0.877 s ± 0.070 for subject 5, 0.820 s ± 0.027 for subject 6, 0.754 s ± 0.030 for subject 7, and 0.745 s ± 0.052 for subject 8. QT intervals were 0.194 s ± 0.017 for subject 5, 0.173 s ± 0.017 for subject 6, 0.253 s ± 0.028 for subject 7, and 0.182 s ± 0.026 for subject 8. Although all subjects with SMID showed similar RR intervals, QT intervals showed 0.593 times slower than those for three subjects with MD.

The risk of heart condition for subjects with SMID was 0.197, 0.207, 0.115, and 0.184 through the Equation 4. Although the mean value for three subjects with MD was 0.039, the mean value for all subjects with SMID was 0.176. Thus, the risk for subjects with SMID was confirmed 4.497 times higher than that for three subjects with MD.

3.2.2. Results of Phase 2

Figures 4 (b) and (d) show the results of QT-RR relation during MSEs. Figure 4 (b) represents the results for subjects with MD, and Figure 4 (d) represents the results for subjects with SMID.

For the results of subjects with MD for Phase 2, the QT-RR relation for three subjects 1, 3, and 4 was existed near the standard curve. RR intervals for three subjects were 0.682 s ± 0.016 for subject 1, 0.936 s ± 0.019 for subject 3, and 0.765 s ± 0.033 for subject 4. QT intervals were 0.327 s ± 0.014 for subject 1, 0.348 s ± 0.005 for subject 3, and 0.338 s ± 0.007. It was considered that there was no big significant difference during MSE interventions. Meanwhile, the QT-RR relation for subject 2 was apart from the standard curve in spite of MSEs. The RR interval was 1.233 s ± 0.044, and the QT interval was 0.262 s ± 0.008. Compared with three subjects, the subject 2 showed 1.552 times faster RR and 0.777 times slower QT intervals. Although there was no serious significant difference in QT-RR relation during MSEs, it seemed that there was the randomly sudden change of RR intervals as shown in Figure 4 (b).

The risk for three subjects was 0.029, 0.058, and 0.034, however, the risk for subject 2 was 0.200. It was considered that the risk of heart condition for subject 2 with MD was 4.942 times higher than three subjects with MD.

For the results of subjects with SMID for Phase 2, the QT-RR relation for all subjects was still apart from the standard curve. RR intervals were 0.837 s ± 0.054 for subject 5, 0.844 s ± 0.102 for subject 6, 0.755 s ± 0.075 for subject 7, and 0.755 s ± 0.052 for subject 8. QT intervals were 0.191 s ± 0.019 for subject 5, 0.220 s ± 0.041 for subject 6, 0.230 s ± 0.016 for subject 7, and 0.188 s ± 0.028 for subject 8. Although there was no big significant difference in RR intervals, QT intervals for subjects with SMID showed 0.614 times slower than those for three subjects with MD during MSEs.

The risk of heart condition for subjects with SMID was 0.192, 0.166, 0.138, and 0.179. The mean value for subjects with SMID (= 0.169) was 4.170 times higher than that for three subjects with MD. Although there was no big difference in QT-RR relation, it seemed that the SD for both RR and QT intervals got to be larger during MSEs as shown in Figures 4 (b) and (d).

As a result, it was found that the risk of original heart condition for subjects with SMID and subject 2 with MD was averagely 4.677 times higher than that for three subjects with MD. Although there was no significant difference during MSEs. The cause of higher risk for subjects with SMID and subject 2 with MD came from the 0.604 times slower QT interval than that for three subjects with MD in this study.

4. Discussion

4.1. Results of nose temperature and RR interval during multi-sensory environment interventions

Thermal imaging, by harnessing the body’s naturally emitted thermal irradiation, enables cutaneous temperature recordings to be measured noninvasively, ecologically, and contact free [28],
The autonomic nervous system (ANS) is at the forefront of biological heat displays, controlling unconscious heart rate, breathing [30], tissue metabolism, perspiration, respiration, and cutaneous blood perfusion, providing grounds for observations of emotional inference to be made. Thus thermal imaging is considered an upcoming, promising methodology in the emotional arena. Driven by sympathetic nerve, observations of affective nature derive from muscular activity subcutaneous blood flow as well as perspiration patterns in specific body parts. Figure 5 shows the results of measured nose temperature (a) and RR interval (b) during MSE interventions. Although it could not be seen any difference of facial expressions and body movements by infrared camera as I mentioned in Figure 1, it was found that there was the relationship between the nose temperature and the RR interval during MSE. It was discussed that the ANS activity made change of the nose temperature and RR interval through the effect of MSE. However, the thermal image had the limitation because it was impossible to see any change of QT interval.

4.2. Necessity of monitoring and classifying the high-risk candidate

Behavioral and psychological symptoms (BPS) affect quality of life (QoL) for patients with disabilities, family, and caregivers. Nonpharmacological interventions are the preferred first line of treatment, although some patients with disability benefit from pharmacological treatment, many drugs have been shown to provide only modest benefits, are not tolerated by a wide number of patients, and may even be harmful [31]-[33]. There are many types of nonpharmacological approaches to reducing BPS, it is well-known that the multi-sensory environment (MSE) interventions indicate the sensorial interventions in general: light, music, therapeutic touch, and multisensory stimuli [34], [35].

Overall, related studies support efficacy of MSE in reducing BPS, potentially improving QoL for patients with disabilities and caregivers [1]-[5]. However, these studies failed to offer conclusions on the timing of MSE therapy, the frequency with which it should be used, or how to identify candidates.
who would benefit from MSE therapy [10]. Furthermore, most of studies failed to show that the intervention was more effective than other potentially less expensive therapies, such as reading to and talking with an individual. In addition, environmental interventions should be implemented with careful consideration to the individual preferences and sensitivities of patients with disabilities in order not to induce BPS through unintended overstimulation [9].

Although the relationship between emotion and health continues to reverberate across medical and psychological sciences, most of caregivers would like to believe that emotions play a role in maintenance of health or development of disease. Then most of them hope that cheerfulness can help to alleviate and cure illness while keeping patients’ emotions in balance at all times. Thus, although most of caregivers have very busy days, they have tried to provide some nursing services or activities for patients with disabilities [6]-[8]. However, it is difficult not to tell that some MSE interventions sometimes tend to be biased by the emotion of caregivers to prepare. Although it is impossible to decide the clear relationship between the health condition and the level of overstimulation with the only experimental results of this study, the results of the present study suggested the necessity for monitoring and classifying the high-risk candidate through the heart condition for patients with disabilities. It was discussed that subjects with impairments of the autonomic regulation such as SMID in this study should be considered through experimental results.

4.3. Possibility of short QT syndrome

Then, autonomic tone influences RR interval variation and the QT interval. Both RR and QT intervals may improve characterizations of sympathovagal control and estimation of risk of primary cardiac arrest. Through the literature results [24], it was well-known that the risk of primary cardiac arrest (odds ratio [95% CI]) was 0.95 [0.73 ∼ 1.23] at low RR and QT intervals, 1.23 [0.97 ∼ 1.57] at high RR and QT intervals, and 1.55 [1.16 ∼ 2.06] at low RR and high QT intervals. Although it was difficult to decide whether the RR interval was low or high, it was considered that the QT interval for this study was low as shown in Figure 4. Short QT syndrome (SQTS) is a rare, inheritable channelopathy of the heart characterized by abnormally short QT intervals on the ECG and an increased propensity to develop atrial and ventricular tachyarrhythmia in the absence of structural heart disease [36]. Since its recognition in 2000, significant progress has been made in defining the clinical, molecular and genetic basis of SQTS as well as the therapy options.

The experimental results of the present study suggested that the risk of original heart condition for all patients with SMID and subject 2 with MD was averagely 4.677 times higher than that for the three patients with MD. Unfortunately, the QT interval for all these subjects with the higher risk was much lower than the general QT interval of 0.330 as shown in Figure 4. That means that these higher-risk candidates could be SQTS. The serious problem was that nobody of caregivers and family knew the possibility of SQTS for these subjects with the higher risk at that time.

5. Conclusions

Most of caregivers provide multi-sensory environment (MSE) interventions to patients with disabilities because cheerfulness can help to alleviate and cure illness while keeping patients’ emotions in balance at all times. However, the results of present study suggested that there was the necessity for monitoring continuously and classifying high-risk candidates of cardiac arrest because the unintended strong overstimulation could have a negative impact of MSE interventions on heart condition for patients with disabilities. Although this study failed to decide the definition of proper stimulation amount for patients with disabilities, it is important that candidates for MSE should be considered after preliminary checks to prevent the risk of cardiac arrest.

6. Patents

There was no patents resulting from this study.
**Author Contributions:** H. Jeong did the formal analysis, investigation and so on before the Writing-original draft preparation, M. Kido did the writing-review and editing, and Y. Ohno did the supervision.

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**Conflicts of Interest:** The authors declare no conflict of interest.

**Abbreviations**

The following abbreviations are used in this manuscript:

- MSE: Multi-sensory environment
- QT interval: Time taken from when the cardiac ventricles start to contract to when they finish relaxing
- RR interval: Time between beat to beat
- MD: Muscular dystrophy
- SMID: Severely motor and intellectual disabilities
- SQTS: Short QT syndrome

**References**


